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Development of SIs on Solid Waste Management Through Selection: A Review

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Along with the development of the nation, waste generation has been one of the critical issues that need immediate attention in a country. Effective and sustainable waste management system needs to be in place to carefully manage the waste generated, especially in the urban areas. Therefore, there is a need for the development of Sustainable Indicators (SIs), to continuously measure and monitor the sustainable performance of solid waste management system. This paper reviewed all the existing SIs that have been developed since the 1990s to monitor and measure the performance of solid waste management systems. The developed SIs are carried out through selection and aggregation processes. However, in this paper, only the development through selection is focused, where it usually adopts the Driving State-Force-State model. Although most developed SIs concentrated on the entire waste management system of an entire city, there are some SIs focused either on specific waste streams, or on specific waste management stages. Nevertheless, the developed SIs covered all the sustainability aspects of the waste management system, which are: economy, social and environment.

1. Introduction

Wastes are generally classified as hazardous or non-hazardous waste. They are said to be hazardous when they exhibit the characteristics of toxicity, corrosivity, ignitability and reactivity (EPA, 2009). Examples include electric light bulbs, batteries, discarded medicines and automotive parts (UNEP, 2004). Wastes that do not exhibit these characteristics are classified as non-hazardous. Non-hazardous wastes are further classified into different categories based on their sources (Nag, 2005). For instance, wastes generated from residential locations are known as residential wastes while those generated from commercial locations are known as commercial wastes. The major component of non-hazardous waste is municipal solid waste (MSW) (Tarmudi et al., 2012). Municipal solid waste (MSW) is known as trash or garbage and consists of everyday items that are used and discarded. These include product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances and batteries emanating from homes, schools, hospitals and businesses (EPA, 2003). UNEP (2004) has characterised the major types of MSW into food or organic waste, paper, plastic, rags metal and glass, which are collected and sent for incineration, recycling, or disposal to MSW landfills (Stapleton, 2004). However, EPA (2010) has not included materials like construction and demolition debris, municipal wastewater treatment sludge and non-hazardous industrial waste in this category, even though these materials may also

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be disposed in landfills as MSW. Nevertheless, the definitions of MSW provided generally are in the same domain. MSW is the biggest environmental problem facing developing countries (Ayuba et al., 2013) and has gained global attention. Decoupling waste generation from wealth creation has always been a challenging hurdle (Harris and Roach, 2013). Globalization, industrialization and rapid economic development have led to a disturbing and increasing rate of solid waste generation (Akkucuk, 2015). The amount of waste generated is also directly related to rapid growth in population and urbanization (Budhiarta et al., 2012). With increased income and improved living standards, expenditure on goods and services has correspondingly increased. This has increased the amount of waste generated (World Bank, 2012). This situation has raised public attention and concern to the organization of MSW collection services especially in developing countries. It is even compounded by the unknown quantity and type of MSW collected, the amount recovered or recycled, the inadequate selection of final disposal sites, and inefficient reutilization and recycling programmes (Buenrostro and Bocco, 2003). Any available data related to solid waste is limited to those managed by individual local authorities and waste contractors, which are very difficult to access and obtain (Luk and Soon, 2007). Reliable information on solid waste characteristics that are important for the planning of disposal methods are hard to obtain or not updated (Idris et al., 2004). Badgie et al. (2012) reported that solid waste analysis and data for major towns and cities have not been properly documented. This becomes an obstacle when correct information is required for innovation and future planning in waste management (Yahaya, 2012), as well as in the monitoring of performance of solid waste management systems (Luk and Soon, 2007). Therefore, there is a need for the development of SIs to continuously measure and monitor the effectiveness of the existing solid waste management system. Moreover, it can depict clearly the sustainable performance of waste management system, it can also link clearly to the sustainability policies adopted by the government. This paper aims at reviewing all the sustainability indicators that have been developed in relation solid waste management. The review of SIs is divided into two parts: selection and aggregation. Generally, the development of SIs through selection does not require any mathematical formulae or aggregation but are only agreed upon by a group of professional experts. Meanwhile, the development of SIs through aggregation involves mathematical equations and formulae. In this paper, only the development of SIs through selection are discussed.

2. Developed SIs Through Selection

2.1 Era of 1990s

International organizations started showing interest and concern on environmental issues and sustainable development from the 1990s. Since solid waste management is considered as one of the important aspects of sustainable development, SIs are developed to measure and monitor its performances. In 1995, the Commission of Sustainable Development (CSD) of the United Nations (2007) agreed on a work programme on indicators of sustainable development. The work programme included a list of approximately one hundred and thirty (130) indicators organized in the Driving Force-State-Response Framework. In this framework, Driving Force indicators represent human activities, processes and patterns that impacted on sustainable development. The State indicators indicate the State of sustainable development and responses to change in the state of sustainable development. Among all the indicators of sustainable development established, there were five (5) SIs specifically on solid waste management. Two (2) of them are Driving Force indicators, while the rest are Response indicators. In pursuance of this objective, the Mediterranean Commission on Sustainable Development published a set of SIs in Blue Plan/Mediterranean Action Plan (MAP) in 1996 (Chabason et al., 2012). It was based mainly on the extension of the Pressure-State-Response (PSR) model developed by the Organization for Economic Cooperation and Development (OECD) at the end of the 1980s (Gauci, 2001). Instead of just focusing on municipal and household wastes, it was extended to hazardous and industrial wastes, including their adverse impacts on the environment. It was documented that there are ten (10) SIs listed under the Environment (Solid Waste) category. Four (4) are Pressure indicators, two (2) are State indicators and four (4) are Response indicators. The two international organizations had developed each of their own sets of SIs based on a similar model: driving force or pressure, state and response model. Meanwhile, in the same year, with the aim of helping local governments in Brazil to monitor, make decision and judgement, Sergio (1996) selected an extensive set of SIs that focused solely on solid waste management. Previously, both United Nations Commission of Sustainable Development and Mediterranean Commission on Sustainable Development had focused more on the big picture: sustainable development. As solid waste management is one of the important aspects in sustainable development, only a few SIs that focused on solid waste management were produced. Sergio (1996), using PICABUE method, came out with an impressive set of SIs that covered MSW management by stages. There are six (6) principal stages of solid waste management defined by Sergio (1996), which are: MSW Generation, Storage, Collection, Transportation, Treatment and Disposal. Reference indicators were defined for each of these six (6) principal stages. These were being augmented to produce seventy-nine (79) SIs. In 1997, the Statistical Office of the European Communities, known as EUROSTAT, conducted a pilot study entitled "Indicators of Sustainable Development (SDI)" in line with the methodology of United Nations Commission of Sustainable Development (1995). EUROSTAT (2001) reported that they found some indicators recommended by United Nations Commission of Sustainable Development that are not relevant for the European Union. After careful reviewing the indicators, EUROSTAT (2001) narrowed down the indicators relating to solid waste management to generation of industrial and municipal waste, expenditure and waste management and rate of waste recycling and reuse. In 1999, EUROSTAT, with the aim of constructing a framework of Environmental Pressure Indicators (EPIs) development for ten (10) key environmental policies, published sixty (60) EPIs in ten (10) key areas in her publication "Towards Environmental Pressure Indicators, for the EU – First Edition" (EUROSTAT, 2001). With waste being one of the key environmental factors, a list of ten (10) core ranked pressure indicators on waste were produced. A second edition of these EPI indicators was released in 2001. EUROSTAT also agreed to take the lead in developing a small set of Environmental Headline Indicators at EU level from 1999 to 2000, As a result, two (2) Headline Indicators on waste were produced (EUROSTAT, 2001).

2.2 Era of 2000s

EUROSTAT published the second edition of EPI indicators on waste in 2001. After careful revision and review, EPI indicators on waste were reduced to five (5) from a list of ten (10) core ranked pressure indicators. EUROSTAT (2001) noted that although there are differences in the reference policy framework and assumption for identification, SDI (UN based) and EPI (expert defined) are almost similar. The Organization for Economic Cooperation and Development (OECD) had initiated the usage of Pressure-State-Response Model (PSR) in 1991 to categorise environmental indicators based on their causal relationship with environmental issues. However, for the SIs that focused on waste, five (5) SIs were published on "OECD Environmental Indicators: Development, Measurement and Use" in 2003. Boer et al. (2007) developed a waste management assessment tool that supported adequate decision making in the planning of urban waste management system by allowing the creation and comparison of different scenarios and considering three basic subsystems: temporary storage, collection and transport, and treatment, disposal and recycling. The SIs proposed by Boer et al. (2007) looked into economic and social aspects of the three subsystems. It covered economic sustainability, economic efficiency (equity, dependence on subsidies, social sustainability of temporary storage, collection and transport), and waste treatment. The SIs ranged from the cost of municipal solid waste management to the physical environment of the three subsystems. Zabaleta (2008) reported a total of sixty-eight (68) indicators organized under seventeen (17) themes that were designed to evaluate the sustainability of Waste Treatment Techniques (WTT) for MSW in a specific situation. Two (2) indicators focused on waste generation and management under the theme of consumption and production patterns, another two (2) indicators under the theme of waste and characteristics, one (1) indicator under the theme of legislation framework, and one (1) under the theme of geographical conditions.

2.3 Era of 2010s

Arendse and Godgrey (2010) identified ten core indicators for National State of Environment Reporting in South Africa. They adopted Pressure-State-Response Model and took consideration of waste generation and waste reduction. Three of the indicators were under waste generation while seven indicators were put under waste reduction. In their opinion, these were adequate enough to report on the state of environment with respect to waste management within South Africa. In 2011, Chavez et al. (2011) developed an assessment tool through a set of indicators integrated into Driving Force-Pressure-State-Impact-Response (DPSIR) model that measured the effectiveness of the waste management programs. The model had indicators for causes, pressure, state, impact and response where the status of each criterion was evaluated. Ten criteria were identified, along with sixteen indicators that were organized under environment, economic and social criteria. Agamuthu (2012) published a set of eight indicators on waste recycling system with the following objectives: to prevent waste, reduce energy usage, reduce air pollution from incineration and water pollution from landfilling, and reduce greenhouse gases (GHGs) emission in comparison with virgin production. Strictly focusing on waste recycling, the set of indicators covered the emission of carbon dioxide (CO_2) and the degree of motivation in the sorting plant. This differed from previous works that had been carried out as the indicators were targeted only on waste recycling systems. In 2013, five different sets of SIs on MSW were developed by different authors, and the comparisons between each set of SIs on MSW are shown in Table 1.

The latest developed set of SIs on municipal solid waste management was by Parekh et al. (2015). They assigned weights to each identified indicator that monitored the performance of municipal solid waste management using Analytical Hierarchy Process (AHP). A total of 41 indicators were organized under eight (8) themes, where these indicators were identified through brainstorming sessions, structured interviews and group discussions with experts.

Table 1: Comparison of Sustainability Indicators on Municipal Solid Waste Management System Developed at year 2013

Author	Differences	Similarity
Yuan (2013)	The developed SIs focused only on construction and demolition waste.	All five (5) sets of SIs included all sustainability aspects: economic, environment and social. Moreover, these five (5) indicators were used to measure and monitor the performance of waste management system.
Alsami et al. (2013)	Adoption of Driving Force-State-Response model to develop the SIs.	
Gamberini et al. (2013)	Engineering indexes are used as SIs, which covers the aspects of environment, economic and social.	
Chandrasekharan et al. (2013)	Environmental Performance Indexes (EPIs), ranking of states and options suggesting for devolving central funds to states of India was adopted, that focused only on three waste stream: municipal solid waste, bio-medical waste and hazardous waste.	
Wilson et al. (2013)	The developed set of SIs was tailored to integrated and sustainable waste management that benchmark the performance of a city, while monitoring the changes at the same time. It covered extensively on policies, waste composition, MSW management stages, financial aspects, environment aspects and social aspects	

3. Conclusions

The development of SIs through selection started in the era of 1990s. Both international organizations and environmental researchers came out with respective sets of SIs to measure and monitor the performance of solid waste management system. The Driving Force-State-Response model is commonly adopted at the beginning of the SIs development. Extensions and improvements are made on the existing Driving Force-State-Response model to meet with the current needs and situations. Some of the developed SIs focused on certain waste stream, while some focused at certain stage of the waste management. For instance, Wilson et al. (2013) developed Environmental Performance Indexes (EPIs), a set of SIs that looked into the management of municipal solid waste, bio-medical waste and hazardous waste. On the other hand, Agamuthu (2012) published a set of eight indicators on waste recycling system. It covers all the environment aspects (air, land, water and waste), economic aspects and societal elements. Nevertheless, the developed SIs are focused on the waste management system of the whole city. There are some SIs are specifically developed for a particular city by environmental researchers instead of international organizations. SIs can be served as an important monitoring and measurement tool for a city to identify the performance of the existing waste management system, as well as planning for a new waste management system. Therefore, it is crucial for the development and implementation of SIs, as an assessment tool for a city on its waste management system.

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